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Final Report

I. Title: Harmful algal blooms (HABs) and their impacts on shellfisheries and finfisheries in western Washington

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II. Abstract

The report describes field and laboratory work proposed and completed during this project and covers the period 1 August 1998 - 31 January 2003. This period overlaps with our previous Saltonstall-Kennedy project "Domoic acid, diatoms, and the shellfish industry in western Washington" that covered the period 1 February 1996 - 31 July 1999. Here we include information on the field guide to local phytoplankton and additional information on coastal and Puget Sound/Hood Canal monitoring.

III. Executive Summary

This report describes the field guide to local phytoplankton, "A Taxonomic Guide to Some Common Marine Phytoplankton," and provides additional information and results of twice-monthly coastal and Puget Sound/Hood Canal phytoplankton and environmental monitoring.

The field guide was published by Biopress Limited, Bristol, UK, in November 2002. It consists of 195 pp. and includes photographs, descriptions and distribution records for 134 species, a brief description of the major taxonomic groups of phytoplankton that have harmful or potentially harmful species, a discussion of sampling methods and sample analysis protocols, a glossary of terms, and references. The book provides an easy way for anyone from school children to professions who have access to a microscope to identify some of the common marine phytoplankton found in temperate waters around the world.

The field monitoring was done at sites with four distinct hydrographic regimes that vary by temperature, salinity and nutrient regimes. Potentially harmful species occurred in all months except March 1999 and at all sites except for *Alexandrium catenella* which was not positively identifed from Hood Canal. The open coast beaches are affected by upwelling which may bring potentially harmful cells to the coast. Puget Sound sites are more affected by local wind and tide mixing processes and the breakdown of stratification. Blooms were rarely seen which suggests that our sampling interval was too broad and sampling mustbe done much more frequently in order to identify events that will affect razor clams and other shellfish.

IV. Purpose

A. Description of problem or impediment of fishing industry addressed

Harmful algal blooms (HABs) continue to be serious and recurrent problems in western Washington where they affect local economies and human and ecosystem health. The major harmful species here are the dinoflagellate genus *Alexandrium* that causes paralytic shellfish poisoning (PSP) and the diatom genus *Pseudo-nitzschia* that causes amnesic shellfish poisoning (ASP). Other potentially harmful organisms in the area are species in the dinoflagellate genus *Dinophysis* which produces okadaic acid, a known tumor promotor, and causes diarrhetic shellfish poisoning (DSP); and the diatom genus *Chaetoceros* and the raphidophyte species *Heterosigma akashiwo* that kill fish in the wild and especially at aquaculture sites, but have not been linked to human toxicity. Water discolorations (so-called red tides) caused by non-toxic dinoflagellates also occur in western Washington waters and may kill shellfish and other invertebrates due to low oxygen levels that occur as the blooms decay.

The major fisheries affected are the commercial and recreational shellfisheries and finfish growers who raise Atlantic salmon in net pens. The shellfisheries include commercial aquaculture sites throughout northern and southern Puget Sound and the coastal estuaries of Grays Harbor and Willapa Bay where oysters, clams and mussels are raised; the recreational and commercial harvest of razor clams on open coast beaches; and the geoduck harvest in Puget Sound. PSP is the biggest problem for most shellfish harvests, but the recreational and commercial harvests of razor clams and Dungeness crabs on the open coast are frequently affected by domoic acid.

These fisheries are big business for Washington state. The shellfish industry has a commercial value of approximately $100 million with about 2,000 people directly employed by the industry and another 5,000 dependent on the industry. Many of the businesses are small and family-owned, and, although costs of closures due to algal toxins are difficult to estimate, even short closures result in serious economic problems. However, even higher costs are incurred if a product has already been shipped and the grower must pay the air freight to return the product for disposal, which also must be paid for. Seasonal razor clam harvests are primarily recreational with a small tribal commercial harvest. Loss estimates due to marine toxins may be about $12 million if just one season is closed, but since razor clams retain domoic acid often for a year or more, several seasons may be closed resulting in serious economic losses to the small coastal communities that depend on the revenue from the clam diggers.

For finfish, damage due to HABs is primarily limited to salmon farms, although the Washington Department of Fish and Wildlife raises salmon for fisheries enhancement, research, and captive brood stock and some Native tribes raise salmon for early release. Economic losses from *Heterosigma* blooms range from about \$2.5-\$12 million per event. Losses of brood stock are particularly costly to the ecosystem. In a bloom in central Puget Sound in July, 1990, 90-100% of the brood stock for one endangered species, including one-half of that strain's gene pool, were lost (Harrell 1990).

B. Objectives

The goal of the project was to provide improved approaches to the study and mitigation of harmful algal blooms.. Thus, our objectives were to 1) develop and publish a field guide to the common marine phytoplankton in western Washington waters, and 2) continue our monitoring program on Washington coastal beaches and in Puget Sound and Hood Canal.

V. Approach

A. Description of work performed

1. Field guide

A field guide, "A Taxonomic Guide to Some Common Marine Phytoplankton," was produced and published based on colored photomicrographs taken of live material collected during our field monitoring trips (described below), cultures of some organisms received from colleagues, scanning electron microscope photographs of a few species, and descriptions and distribution records from the literature. The book consists of 195 pages, photos of 134 species (78 diatoms, 50 dinoflagellates, and 6 other taxa). It includes a brief description of the major taxonomic groups of phytoplankton that have harmful or potentially harmful species (diatoms, dinoflagellates, raphidophytes, prymnesiophytes, and silicoflagellates), a discussion of sampling methods and sample analysis protocols, a glossary of terms pertinent to phytoplankton, and references. The book is available from Biopress Limited, The Orchard, Clanage Road, Bristol BS3 2JX, England, or in the U.S. from Balogh International, Inc., Publisher's Agents and Distributor, 1911 N. Duncan Rd., Champaign, IL, 61822, and costs \$60.00 plus \$12.00 packing and postage.

The purpose of the book is to provide an easy way for anyone, from school children to professionals, who have access to a microscope to identify some of the common marine phytoplankton species present in temperate waters around the world. The impetus for the guide came from Puget Sound finfish and shellfish growers who need to identify species harmful to their products. This led to a series of workshops for growers and state and federal agency personnel and to the preparation of a series of preliminary guides based on figures photocopied from the literature (e.g., Cupp 1943, Dodge 1982, Gemeinhardt 1930, Hustedt 1930, Larsen and Moestrup 1989, and Schiller 1933, 1937). It is not intended to replace these publications or newer ones (e.g., Throndsen 1993, Heimdal 1993, Hasle

& Syvertsen 1996, Steidinger and Tangen 1996, and Bérard-Theriault et al. 1999), but to supplement them.

2. Field monitoring

a. Beach sampling

Beach sampling at five coastal beaches (2 Kalaloch, Copalis Beach, Ocean Shores, and Grayland) and five Puget Sound/Hood Canal sites (Manchester, Allyn, Twanoh State Park, Hoodsport, and Point Whitney) and occasionally at other sites (Dockton, Sequim Bay State Park, Port Angeles) has been carried out approximately twice monthly since early 1966, weather permitting.

At coastal beaches, samples were collected by a project scientist wading into the surf with a bucket, waiting for a good wave, and scooping up a bucket of water. A 500 ml bottle was filled from the bucket to be used for salinity and nutrient analyses, and the rest of the water was poured through a 25 cm diameter, 20 µm mesh plankton net to concentrate the cells. Temperature, measured in the bucket with a mercury thermometer, and local weather conditions were recorded in a field log. Samples were kept in a cooler containing packets of gel ice for transport to the Seattle laboratory. There, samples for salinity and nutrient analyses were filtered through Whatman GF/F filters and split into a 250 ml bottle for salinity that was kept a room temperature, and a 100 ml bottle for nutrient determination that was frozen until analysis. Salinity was determined using a Guildline Autosal salinometer; nutrient samples wre analyzed in the School of Oceanography's Marine Chemistry Laboratory using standard autoanalyzer methods (Whitledge et al. 1981). Phytoplanktn species were determined by examining a few drops of the concentrated sample under a compound microscope equipped with phase contrast illumination. Several transects were made across the microscope slide, species were identified, and relative abundance determined.

Puget Sound/Hood Canal samples were collected from docks. The salinity/nutrient samples were collected by filling a 250 ml bottle with surface water. Vertical net tows were made from about 5 m to the surface using a 25 cm diameter, 20 µm mesh net with one or more vertical hauls made until cells could be seen in the cod end jar. Samples were processed as above.

B. Project management: individuals performing the work and how it was done

1. Field guide

R. Horner examined most of the phytoplankton samples, took all of the photomicrographs, including the SEM photos (four SEM photos were obtained from colleagues), and wrote all the text.

2 Beach sampling

Beach sampling was done by at least two people on each trip; P. Rudell went on most of the trips with either R. Horner (beaches) or J. Postel (Puget Sound/Hood Canal).

VI. Findings

A. Actual accomplishments and findings

1. Field guide

The field guide was produced and is available for purchase (see above).

2. Field sampling JIM WILL YOU INSERT THE FIGURES FROM THE POSTERS????? NOTE THAT THE FIGURE NUMBERS ARE DIFFERENT THAN THE ONES ON THE POSTERS.

Samples come from four distinct hydrographic regimes (Fig. 1): 1) open coast beaches having gentle slopes, fine sand, and seasonal upwelling, and are the sites of razor clam populations and seasonal surf zone diatom blooms; 2) Puget Sound Main Basin is a fjord influenced by tidal and wind mixing with a seasonal pycnocline and phytoplankton blooms; fish farms occur at some locations; 3) Southern Puget Sound has restricted circulation and low dissolved oxygen and is a possible area for non-point source pollution; shellfish farms are common; 4) Hood Canal is a long fjord with oxygen depletion occurring most of the year; shellfish beds are common and there is a seasonal shrimp fishery.

a Environmental monitoring results

1. Temperature cycles at the ocean beaches were generally synchronous, usually being within 3°C of each other on a sampling date (Fig. 2). The Main Basin of Puget Sound (Manchester) was cooler than either South Sound (Allyn) or Hood Canal (Twanoh, Hoodsport, Pt. Whitney) during summer (Fig. 3).

2. Manchester also had minimal salinity fluctuations than the other sites which were more influenced by freshwater runoff from nearby rivers or increased salinty during coastal upwelling (Figs. 4, 5).

3. There were extended periods of low nitrate (< 0.5 µM) on the ocean beaches with episodic replenishment during upwelling events or seasonal changes in coastal currents (Fig. 6). The Puget Sound Main Basin seldom had < 5 µM nitrate due to strong tidal mixing and weak stratification. In contrast, South Puget Sound and Hood Canal generally had < 0.5 µM nitrate throughout the summer periods (Fig. 7).

b. Species distribution results (Fig. 8)

1. Potentially harmful species were present at one or more sites in all months except. March 1999. All potentially harmful species occurred at all sites except that *Alexandrium* was not positively identified in Hood Canal.

2. *Alexandrium catanella* was found sporadicaly and never in high numbers at the open coast beaches. In fall, 1999, it was present at Allyn in southern Puget Sound when record high levels (nearly 7000 µg/100 g shellfish) PSP toxin were reported by the Washington Department of Health.

3. *Pseudo-nitzschia* spp. were common on the open coast beaches with blooms at Grayland in July 1997 (no domoic acid reported) and at Kalaloch in September 1998 (record high levels of domoic acid at 287 µg/g in razor clams). *Pseudo-nitzschia* spp. were also common in Puget Sound and Hood Canal, but rarely occurred in high concentrations.

4. *Dinophysis* spp. were present primarily in spring to summer and at all sites.

5. *Heterosigma akashiwo* was rarely present, but a small bloom occurred at Allyn in October 1999. A huge bloom (> 10^8 cells L^{-1}) first found by the Washington Department of Ecology and identified by us, covered Hood Canal in September 2000 after our monitoring ended.

c. Conclusions

1. *Pseudo-nitzschia* spp. frequently occur on the beaches, but rarely in bloom proportions. The few blooms that have been seen have been short-lived. Different species may be dominant at different times.

2. *Alexandrium catenella* was rarely seen in beach samples. A major PSP event in the coastal estuaries in the fall of 1997 did not affect razor clams on the open coast beaches.

3. Our monitoring was probably not frequent enough to detect some, possible most, beach blooms given the often short-term wind and current variability.

4. Although all the ocean beaches experience similar temperature conditions, they are separately influenced by local freshwater sources and upwelling events.

5. The Main Basin of Puget Sound is less variable in temperature, salinity, and nutrient concentrations than the other inland locations we sampled. Mixing processes in the Main Basin weaken water column stratification enough to prevent prolonged nutrient depletion during bloom events.

B. Discuss significant problems if they resulted in less than satisfactory or negative results

There were no significant problems during the course of the project. Adverse weather conditions sometimes curtailed sampling especially on the open coast beaches dduring winter, but these were not significant.

C. Description of need for additional work

Our work showed the necessity of sampling more frequently, especially on the open coast beaches where, during fall storms, *Pseudo-nitzschia* spp. may be brought onto the beaches and affect razor clams. Frequent sampling, twice per week during spring, summer, and fall and once per week during winter, is now being done (since August 2000) by the Olympic Region Harmful Algal Bloom (ORHAB) and has already paid off. The fall 2002 razor clam season was not opened as scheduled for early October because ORHAB project technicians reported increasing numbers of *Pseudo-nitzschia* cells in their samples which lead to domoic acid concentrations in the razor clams above the closure level of 20 ppm.

The source of the *Pseudo-nitzschia* cells is still not known, but there are suggestions that the Juan de Fuca eddy off the Strait of Juan de Fuca and south of Vancouver Island may be a possibility. Data from our samples collected during the McArthur cruises in 1996, 1997, and 1998 (Horner et al. 2000) together with data from earlier Canadian cruises (Forbes and Denman 1991), showed high concentrations of *Pseudo-nitzschia* cells in that area as well as high levels of domoic acid (Trainer et al. 2002). This area will be the site of intensive studies to begin in summer 2003 (ECOHAB PNW, B. Hickey, Principal Investigator).

While we are participating only minimally in ORHAB and are not part of ECOHAB, we can say that our studies have provided much of the impetus for these new, larger studies.

VII. Evaluation

A. Extent to which goals and objectives were met:

1. Our goals were attained by the publishing of the field guide, by posters presented at national and international meetings, and by the publication of two papers (Horner et al. 2000 and Trainer et al. 2002) which include data from our project.

2. The goals were not modified.

B. Dissemination of project results:

Project results will be disseminated through book sales, by posters presented at national and international meetings (Postel and Horner 2000, 2001; Postel et al. 2000, 2001), and by publication of our data in the scientific literature (Horner et al. 2000; Trainer et al. 2002).

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